Display Monitor Measurement Methods

Under Discussion by
EIA (Electronic Industries Association) Committee JT-20

Part 2: Color CRT Monitor Performance

Version 2.0
July 12, 1995

Submitted to EIA JT-20 by:

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Dear Monitor Professional,

The National Information Display Laboratory would like to present for your consideration *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Version 2.0.* We would also like to express our gratitude to members of the SID Standards and Definitions Committee, the U.S. Government, members of VESA, NIST, and the display industry, who have provided many highly constructive and valuable suggestions for improving our earlier version of this document. We encourage you to review this document and let us know how we can further improve it to meet your needs.

The goal of this document is to provide practical, tested procedures for obtaining and reporting consistent and repeatable performance measurements of color CRT displays, **especially those used in imagery analysis**. The reported results of these measurements can be used to determine whether a candidate display can meet the needs of Image Analysts and other critical users, such as radiologists in the medical imaging community. This document enables users to easily make an objective comparison when choosing between candidate displays. The goal is not to reinvent, but to identify, incorporate, and revise as appropriate, measurement standards that other standards-generating bodies have established.[1] The establishment of such measurement and reporting standards, and promotion of their use, will provide a common language by which display users can communicate their needs to display manufacturers, better enabling the manufacturers to recognize the critical performance criteria which must be met in order to successfully provide increasingly higher quality, more cost-effective color CRT displays to the user.

We believe this document, along with its companion NIDL publication 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Version 2.0,* presents a practical and sufficiently detailed set of measurement procedures for evaluating the performance of color CRT monitors for imagery applications. It owes much to existing standards documents and to the people and organizations who created them. Existing standards documents provide established methods for evaluating color CRT displays targeted for text or graphics applications. This document is intended to be complementary to existing standards by addressing the performance issues which effect whether the Image Analyst can reliably and efficiently perceive low contrast detail in color images.

A standard set of measurement evaluation procedures and method of reporting the results for high-resolution displays benefits the user because it:

- provides a quantifiable means to judge the performance of the display in an objective and meaningful way;
- eliminates the need for display evaluators to spend time identifying and gathering other test procedure documents generated by a variety of organizations;
- results in information which is useful to help reduce the time required to select a display that optimally meets the critical needs of the user;

[1] Kelley, E. F., et al., *A Survey of the Components of Display-Measurement Standards*, SID 95 DIGEST, pp. 637 - 440.

- avoids excessive costs of purchasing over specified displays when standardized measurements are used to provide the exact performance criteria for selecting a display;

- promotes a common language to describe the exact requirements of the user, thus enabling the display industry to develop monitors that better meet users' needs.

Applying the previous version of the NIDL measurement procedures, NIDL and NIST successfully completed the first-known round-robin measurements on one CRT display monitor using two very different sets of measurement equipment but working from the same set of measurement procedures. The results, identical to within small measurement errors, were presented at SID [2] where manufacturers were encouraged to conduct round-robins with NIST to confirm that their equipment or monitor data sheets provide information based on standardized measurement practices.

Again, we thank NIST, the members of the SID Standards and Definitions Committee, the U.S. Government, and contributors from VESA and the display industry who provided many highly constructive and valuable suggestions for improving our earlier version of this document. We especially want to state our appreciation to Edward Kelley, Danny Gross, Carlo Infante and Howard Okamoto. We would also like to acknowledge the dedicated efforts of NIDL retirees, Peter Wojtowicz and Arthur Miller, for their contributions to the conception and development of this document.

As we work towards gaining acceptance of each of these sets of test procedures as national and world standards through established channels, including: SID, EIA, ANSI, ISO and VESA. We look forward to receiving comments. Please send them in as soon as possible, either by email to <NIDL@NIDL.org>, or by surface mail to:

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Sincerely,

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2 Bechis, D. J., et al., *Display-Measurement Round-Robin*, SID 95 DIGEST, pp. 641 - 644.

Preface

Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Version 2.0, along with its companion document *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Version 2.0,* are intended to satisfy a need expressed by many users and evaluators of displays in the government, medical, and commercial communities, as well as by manufacturers of displays and display systems, for a self-contained, comprehensive document of evaluation procedures for characterizing the photometric and electrical response related to the performance of monochrome and color CRT display monitors. These docu-ments enable evaluators in different laboratories to conduct standardized measurements of aspects of CRT monitor performance and to attain the same results when measuring the same display.

In turn, this benefits purchasers and manufacturers of CRT monitors by providing a means of specifying and measuring display performance in a common, meaningful way. By providing standardized procedures that can be consistently repeated, the documents also benefit users who need to track the performance of their displays over time and perform quality control adjustments. By being self-contained and as comprehensive as possible, the documents enable users and manufacturers to rapidly access, read, and implement tests of display systems, and eliminate the need of display evaluators to spend time identifying and gathering test procedure documents generated by a variety of organizations.

The procedures are intended to be applicable to CRT monitor displays of all performance levels, covering the range from low resolution CGA displays, to high resolution color displays with greater than 2500 x 2000 pixels resolution.

Each issue mentioned below represents an important need that evaluators and specifiers of display systems have. Some of these needs are addressed by existing standards documents for particular display user tasks. Other issues stated here represent needs that call for additional scientific and human factors studies, and the generation of a separate standards document.

It is important to state what this document is not intended to achieve. The document *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Version 2.0* does not:

1. specify which procedures to use to evaluate the capability of a display system to enable its user to accomplish a particular task with the maximum of efficiency and reliability;

2. specify or recommend the values or the ranges of values which the display system must achieve in a specific test procedure or set of test procedures for the display system to "qualify" for use in a particular task;

3. address which measured performance parameters can be traded off against one another and by how much and still allow the display to achieve a level of performance that is acceptable for a particular task;

4. rule out or judge alternative test procedures that may have been developed to measure the same physical effect. Such test procedures may employ different laboratory measurement equipment, different measurement procedures, and different analysis techniques. However, since the goal is to provide a common basis for comparison of monitor performance parameters, discrepancies in measured performance parameters obtained by different test procedures are unacceptable and need to be resolved.

These test procedures for evaluating critical performance parameters, including resolution, luminance uniformity, and geometric distortions, have been condensed from an earlier draft of a different NIDL document *Test Procedures for Evaluation of CRT Display Monitors Version 3.1 dated 6/15/92.* Additional test procedures for measuring parameters such as spot size and video amplifier bandwidth are useful as diagnostics and will be developed for inclusion in a future document.

SAMPLE EVALUATION DATASHEET

I. MANUFACTURER'S DATA

Manufacturer Name	Company ABC
Model #	1A
Monochrome or Color	Color
Screen Diagonal	21 inches
Horizontal Scan Rate	89.71 kHz
Vertical Scan Rate	72.00 Hz
Image Size (H x V)	380.0 mm x 284.5 mm (14.96 x 11.20 inches)
Addressable Pixel Number	1600 x 1200
Pixel Size	0.237 x 0.237 mm (9.35 x 9.33 mils)
Dot or Stripe Pitch	0.28mm (11.0 mils)

II. MEASURED PERFORMANCE

A. Performance Related to Luminance

Warmup Time	20 minutes to ±1%
Full Screen Luminance	103 cd/m^2 (30 fL)
Luminance Uniformity	76.67 - 96.13 cd/m^2
Color Coordinates	x = 0.282, y = 0.295
Color Uniformity	2.9% in x, 4.1% in y
System Gamma	W=2.45 R=2.35 G=2.53 B=2.40
Luminance Stability	≤12%

B. Performance Related to Geometry

Waviness	≤ 0.4%
Linearity	≤ 2.6%
Raster Size Stability	≤ 0.1%
Jitter	< 0.13 mm (< 5 mils)

C. Performance Related to Resolution

50% Linewidth (HxV):	
center	0.328 x 0.287 mm (12.9 x 11.3 mils)
average periphery	0.340 x 0.284 mm (13.4 x 11.2 mils)
worst location (@ 10:00)	0.399 x 0.290 mm (15.7 x 11.4 mils)
Convergence (HxV):	
center	0.061 x 0.109 mm (2.4 x 4.3 mils)
average periphery	0.163 x 0.168 mm (6.4 x 6.6 mils)
worst location (@ 8:00)	0.371 x 0.229 mm (14.6 x 9.0 mils)
Faceplate Reflectivity specular	20%
diffuse	3%
Contrast Ratio	75:1
Halation	≤ 5.6%
1-on/1-off Contrast Modulation (HxV):	
center	43 x 31%
average periphery	16 x 38%
worst location (@ 8:00)	6 x 46%
Resolvable Pixels (HxV) (screen average)	
@ C_m = 25%	1412 x 1174
@ C_m = 50%	1047 x 970

D. Reliability and Life Performance

MTBF	10,000 h
Cathode life at 100 cd/m^2 luminance	10,000 h

E. Evaluator

Organization Name	Testing Lab XYZ
Address	Tucson, AZ
Phone	(___) ___-____
Evaluation Dates	3/1/93 to 4/1/93
Equipment Used	Photo Research PR-704, Microvision SS100

F. Additional Performance Measurements Available: (Y_x_ / N__)

CROSS-REFERENCE TO APPLICABLE MEASUREMENT PROCEDURE

A. Performance Related to Luminance

Warm-up Time	4.1 Warm-up Characteristics, Page 11
Full Screen Luminance	3.0 Initial Monitor Setup, page 9
Luminance Uniformity	4.4 Luminance and Color Uniformity, page 12
Color Coordinates	3.0 Initial Monitor Setup, page 9
Color Uniformity	4.4 Luminance and Color Uniformity, page 12
System Gamma	4.2 System Gamma, Page 11
Luminance Stability	4.3 Luminance Stability vs. Fill Factor, page 11

B. Performance Related to Geometry

Waviness	6.1 Waviness, page 35
Linearity	6.2 Linearity, page 35
Raster Size Stability	6.3 Raster Size Stability, page 35
Jitter	6.4 Scan Variability With Time, Page 36

C. Performance Related to Resolution

50% Linewidth (HxV):	5.1 Linewidth, page 17
center	
average periphery	
worst location (@ 10:00)	
Convergence (HxV):	5.3 Convergence, page 27
center	
average periphery	
worst location (@ 8:00)	
Faceplate Reflectivity specular, diffuse	4.5 Reflectance, page 15
Contrast Ratio	4.7 Contrast Ratio, page 15
Halation	4.6 Halation, page 15
1-on/1-off Contrast Modulation (HxV):	5.2 Contrast Modulation, page 21
center	
average periphery	
worst location (@ 8:00)	
Resolvable Pixels (HxV)(screen average)	5.2 Contrast Modulation, page 21
@ C_m = 25%	
@ C_m = 50%	

D. Reliability and Life Performance

MTBF Cathode life at 100 cd/m^2 luminance	4.8 Lifetest, page 15

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CONTENTS

1.0 INTRODUCTION

To be unambiguous, a standardized test procedure for characterizing the photometric response of a CRT display monitor not only must state what needs to be done, but also describe a particular method for accomplishing the task and an example including data analysis. As stated in the Preface, alternative methods of accomplishing the same task using different equipment, different procedures, and/or different analysis techniques are acceptable if they are equivalent, that is, they yield the same measured performance parameter(s) when applied to the same CRT display.

<u>To achieve this purpose, each procedure is structured in the following manner:</u>

- **Objective** states not only what physical performance parameters are to be measured, but also provides a rationale for the measurement (why this is an important measurement for evaluating a CRT monitor).
- **References** states what standardized measurement procedures may already exist for this performance metric. Furthermore, References states whether the measurement procedure contained herein is identical to the standardized existing procedure or whether the existing measurement procedure has been modified or abandoned. Reasons for modifications or abandonment are provided.
- **Equipment** provides a list of necessary generic measurement devices. Specific examples of commercial measurement equipment are provided in Section 2.0 of this document, without qualification or endorsement, and without the intent of providing a complete list.
- **Procedure** describes a procedure for generating the data necessary for characterizing this particular aspect of display performance.
- **Data** provides a description of the output of fully implementing the Procedure, and in many cases, a representative sample sheet for tabulating the data is included.
- **Analysis** explains how the data is treated mathematically and presents the equations used to arrive at the final measured performance parameter or set of parameters.
- **Output** presents a sample of the Analysis results.

<u>This document is divided into the following sections:</u>

- **Section 2.0** lists the generic equipment required to conduct the measurements, provides examples of the required photometric and electrical equipment, and provides instructions on the calibration of the photometric equipment. Section 2.0 also provides optional measurement procedures to characterize the electrical performance of the video signal generator required in nearly all measurements of the CRT display monitor performance.
- **Section 3.0** provides a standardized procedure for setting up the monitor to be evaluated.

- **Section 4.0** provides additional procedures to characterize the photometric performance of the CRT display monitor system.
- **Section 5.0** contains procedures for performing measurements to determine the most important performance characteristic of a display monitor, its *resolution.*
- **Section 6.0** provides additional procedures to characterize the geometric performance of the CRT display monitor system.
- **Section 7.0** contains a sample of a proposed standard monitor specification sheet for reporting measurement results in a format which enables the display user to make an objective and consistent comparison between candidate monitors.

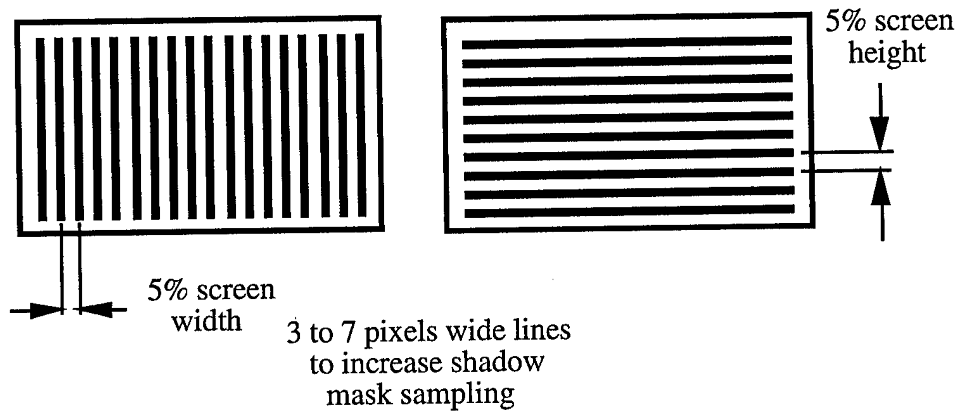
2.0 REQUIRED EQUIPMENT

2.1 Examples of Required Equipment

2.1.1 Video Generator

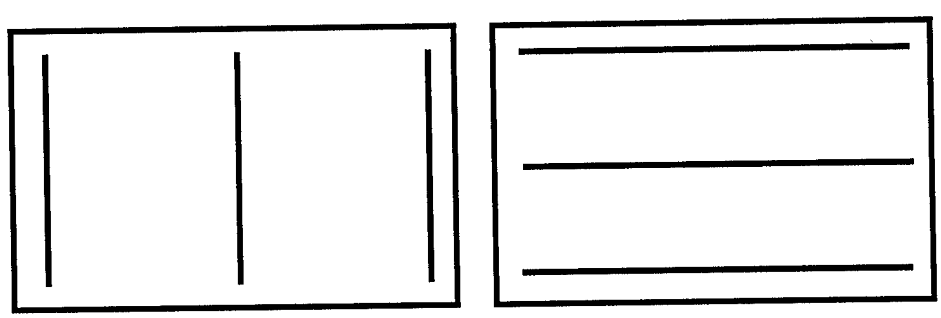
Function: The video generator drives the monitor with input signals for displaying a wide variety of test patterns.

Test patterns: In addition to the test patterns specified in Section 2.1.1 Video Generator in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0*, the programmable video generator used for color displays should also be capable of displaying the following test patterns using multiple-pixels wide lines to increase shadowmask sampling, thus providing better accuracy when determining the position of the center of luminance (centroid) of the line.



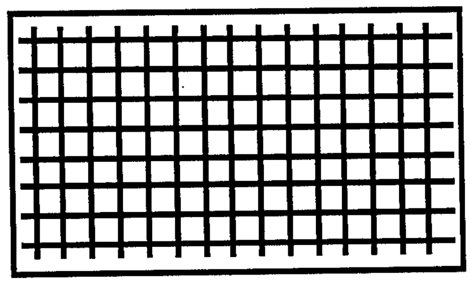
V-grille for measuring horizontal linearity *H-grille for measuring vertical linearity*

Figure 2.1.1-1



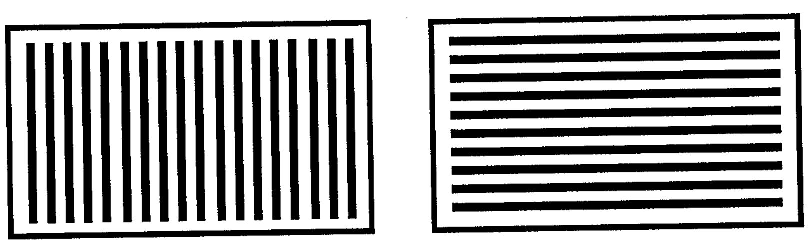
Three-line test patterns with 3 to 7-pixels wide lines to increase shadowmask sampling for measuring waviness and misconvergence.

Figure 2.1.1-2



Crosshatch pattern of single-pixel wide lines for visually assessing misconvergence.

Figure 2.1.1-3



V-grille and H-grille patterns with variable width lines 1 to 5-pixels wide and variable width spacings 1 to 5-pixels wide for assessing moiré.

Figure 2.1.1-4

2.1.2 Spatial Luminance Measurement Equipment

Function: Spatial luminance measurements are required to evaluate contrast modulation, convergence, waviness, linearity, jitter, and raster size of an image displayed on a structured screen such as a shadowmask CRT. Spatial luminance measurements may be performed by slowly moving the image past a slit or round aperture of a photometer either: 1) by mechanically moving the photometer past the image (scanning slit method), 2) by electrically moving the image past the photometer (moving beam method), or 3) by focusing the image onto a spatially calibrated photodiode or CCD linear array [ARP1782]. Some measurement equipment companies provide systems that enable one to move the beam across the raster in sub-pixel increments using programmable time delay circuits to alter the relationship between vertical and horizontal synchronization pulses.

References: ARP1782, *Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays*, SAE, January 1989.

TEPAC 105-9, *Line Profile Measurements in Shadow Mask and Other Structured Screen Cathode Ray Tubes,* EIA, January 1987.

Kawakami, Y., and Palmer, W., *High-Accuracy Convergence Measurements*, SID Seminar Lecture Notes, Vol. I: May 6,1991, pp. M5/1 - M5/26.

Procedure: For color CRT displays, follow recommendations outlined in Section 2.1.2 Spatial Luminance Measurement Equipment in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

Accuracy: In *High-Accuracy Convergence Measurements*, Kawakami and Palmer discuss the relationship between phosphor pitch and image magnification, and the consequential effects on measurement accuracy when using multi-element photosensors such as CCD arrays. Improved repeatability and accuracy are gained by adjusting the sensor optics so that the magnification of the image is such that the phosphor pitch, when imaged onto the sensor, is an integer multiple of the CCD element pitch.

2.1.3 Luminance Measurement Equipment

2.1.3.1 Photometer

Function: Required to measure average area luminance on the display for evaluating raster luminance, system gamma, luminance stability, luminance uniformity, and halation.

Procedure: For color CRT displays, follow recommendations outlined in Section 2.1.3.1 Photometer in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

2.1.3.2 Micro-Photometer

Function: The micro-photometer is required for measuring luminance of peaks and valleys of grille patterns used for evaluating display contrast modulation. For color CRTs, the micro-luminance measurement field must be less than 1/2 phosphor stripe width, or less than 1/2 the diameter of a phosphor dot.

References: TEPAC 105-9, *Line Profile Measurements in Shadow Mask and Other Structured Screen Cathode Ray Tubes,* EIA, January 1987.

Procedure: For color CRT displays, follow recommendations outlined in Section 2.1.3.2 Micro-Photometer in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

2.1.3.3 Luminance Standards

Function: Provide a standard luminance source traceable to NIST for calibrating photometer and spectroradiometer.

Procedure: For color CRT displays, follow recommendations outlined in Section 2.1.3.3 Luminance Standards in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

2.1.4 Color Measurement Equipment

Function: Color measurement equipment may include preferably a spectroradiometer or colorimeter for measuring chromaticity coordinates of display. For color displays, chromaticity coordinates of white and individual red, green, and blue primaries are measured to evaluate color spatial uniformity and variation of white purity as a function of luminance. Use a spectroradiometer with minimum 400 to 700 nm wavelength range. If a colorimeter is used, it should be calibrated to a spectroradiometer.

Procedure: For color CRT displays, follow recommendations outlined in Section 2.1.4 Color Measurement Equipment in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

2.2 Equipment Calibration

2.2.1 Luminance Calibration

Objective: Calibrate luminance measurement equipment using a NIST (NBS) traceable luminance standard as a reference.

Procedure: For color CRT displays, follow recommendations outlined in 2.2.1 Luminance Calibration in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

2.2.2 Color Calibration

Objective: Calibrate color measurement equipment using a luminance standard as a reference.

Procedure: For color CRT displays, follow recommendations outlined in 2.2.2 Color Calibration in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

2.2.3 Spatial Luminance Calibration

Objective: Calibrate spatial luminance measurement equipment using a Ronchi grating as a reference. For the particular optical setup of a CCD or photodiode array, establish the effective size of a single module element in the object plane.

Procedure: For color CRT displays, follow recommendations outlined in 2.2.3 Spatial Luminance Calibration in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

3.0 INITIAL MONITOR SETUP

Objective: BRIGHTNESS, CONTRAST, FOCUS, and CONVERGENCE controls are adjusted following the recommendations of the monitor manufacturer.

Procedure: Display three-beam white to perform the procedures outlined in Section 3.0 Initial Monitor Setup in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

Convergence

Leave convergence as factory configured or follow factory procedures if they are provided.

Color temperature

Leave color temperature as factory configured or follow factory procedures if they are provided. Color displays should be measured for color temperature for an output luminance level of 50% L_{max} as measured at screen center using a test pattern consisting of a square box 1% total screen area in size. The input count necessary to achieve 50% L_{max} must be determined at center screen using the same target. The x, y coordinates are measured directly using a spectroradiometer or colorimeter for comparison with manufacturers specifications.

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4.0 PHOTOMETRIC CHARACTERIZATION

4.1 Warm-up Characteristics

Objective: Determine the transient photometric characteristics of the display device. Find the minimum time required for the display to stabilize to a predetermined luminance level.

Procedure: Follow the recommendations outlined in Section 4.1 Warm-up Characteristics in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

4.2 System Gamma

Objective: Measure the nonlinear photometric characteristic (output luminance versus input drive) of the display as it spans L_{min} to L_{max}. Tonal variations such as intensity and shades of gray are essential for imagery tasks. Typical values for gamma range between 1.5 to 3. The gamma value determines the resolution required for the digital to analog converter and look up table for digital to luminance mapping.

Procedure: Display individual red, green, and blue beams and three-beam white to perform the procedures outlined in Section 4.2 System Gamma in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

4.3 Luminance Stability as a Function of Fill Factor

Objective: The purpose of this test procedure is to determine the luminance stability of the display as a function of the fill factor. Halation, phosphor saturation, video amplifier low frequency response and thermal effects may contribute to luminance instability.

Procedure: Display three-beam white to perform the procedures outlined in Section 4.3 Luminance Stability as a Function of Fill Factor in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

4.4 Luminance and Color Uniformity

Objective: Measure the variability of luminance and colorimetry (chromaticity coordinates) of the white point and of individual primaries (red, green and blue) as a function of time, intensity, and spatial position on the screen. Variability of luminance and color purity impacts the total number of discriminable gray steps. Color CRTs may exhibit shifts in luminance and color purity caused by nonuniformities in the shadowmask as a result of design tolerances, doming and blister. Individual phosphor components may saturate or exhibit a change in persistence as a function of beam intensity.

References: ASTM E1336 - 91, *Standard Test Method for Obtaining Colorimetric Data from a Video Display Unit by Spectroradiometry.*

ASTM E1341 *Standard Practice for Obtaining Spectroradiometric Data from Radiant Sources for Colorimetry.*

MPR 1990:8 *Test Methods for Visual Display Units*, Swedish National Board for Measurement and Testing, December, 1990.

TEP105-11-A, *Measurement of the Color of CRT Screens,* EIA, 1988.

TEP116-B, *Optical Characteristics of CRTs*, EIA, 1989.

ISO/TC159/SC4 N201 *Ergonomics Requirements for Office Work with Visual Display Terminals (VDTs). Part 8, Requirements for Displayed Colours,* December, 1990.

CIE No. 38, *Radiometric and Photometric Characteristics of Materials and Their Measurement*, 1977.

CIE No. 63, *The Spectroradiometric Measurement of Light Sources*, 1984.

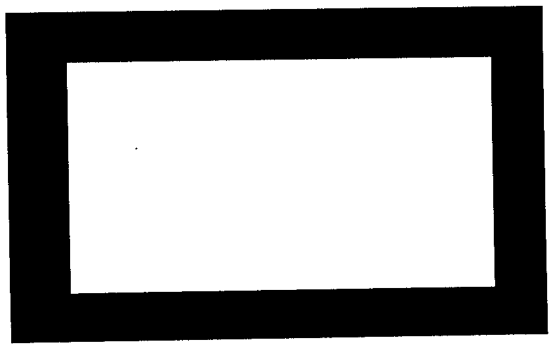
CIE No. 69, *Methods of Characterizing Illuminance Meters and Luminance Meters*, Publication, 1987.

Tchen, H., et al., *Photocolorimetric Measurements of TV and HDTV Display Devices*, Application Notes, SID'92, pp. 75-78.

VESA Standard: Display Specifications and Test Procedures, Version 1.0, Rev. 1.0 , 3 October 1994.

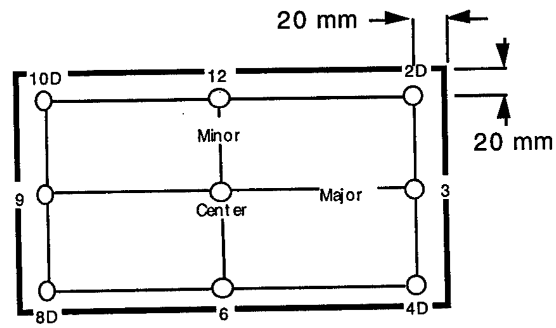
Equipment: Video generator
Photometer
Spectroradiometer or Colorimeter

Test pattern: Full screen flat field as shown in Figure 4.4-2.



Full screen
flat field test pattern

Figure 4.4-1



Nine screen test locations

Figure 4.4-2

Procedure: Measure temporal variation of luminance and CIE chromaticity coordinates at screen center as a function of intensity for a time span of 2 hours for each video input count level. Display a full screen flat field shown in Figure 4.4-1 for four different brightness levels with input counts corresponding to 25%, 50%, 75%, and 100% of L_{max} as determined in Section 3.0. Make measurements every minute during the first 30 minutes, then at longer intervals when changes occur more gradually. For example, the measurement interval should be every 1 minute for the first 30 minutes, then every 5 minutes up to the first hour, and then every 10 minutes after the first hour. Between each set of measurements return the display to L_{min}, and let the display stabilize and the shadow mask cool down for 20 minutes before proceeding to the next set of measurements.

Measure the temporal variation of luminance and color as a function of spatial position on the screen by repeating these measurements at each of the locations depicted in Figure 4.4-2. The locations of corner screen test points are arbitrarily defined. Guidance for selecting alternative test point locations is provided in Appendix B. In addition, measure variations at any other critical points on the screen as deemed by the experimenter.

The procedures described above should be carried out in a darkened environment such that the stray luminance $L_{ambient}$ diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1 mfL). In any case, the value of $L_{ambient}$ should be measured and recorded.

Data: Tabulate the luminance and 1931 CIE chromaticity coordinates (x, y) of red, green, blue, and white for each intensity level as a function of time at each of the nine locations depicted in Figure 4.4-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Sample data:

Table 4.4-1. Sample Data for Spatial Uniformity of Luminance and Chromaticity Coordinates of the White Point for Four Luminance Settings Taken at Nine Screen Positions (in % of L_{max}).

	100% L_{max}			75% L_{max}		
POSITION	**x**	**y**	**cd/m²**	**x**	**y**	**cd/m²**
center	0.275	0.289	101.8	0.274	0.290	76.5
2	0.272	0.285	91.4	0.272	0.288	69.1
3	0.277	0.292	97.7	0.280	0.291	73.7
4	0.271	0.280	64.2	0.272	0.282	49.1
6	0.272	0.282	73.7	0.273	0.285	55.6
8	0.273	0.288	79.8	0.275	0.290	60.8
9	0.277	0.289	88.8	0.277	0.290	68.1
10	0.274	0.292	87.9	0.272	0.292	66.2
12	0.273	0.287	83.7	0.271	0.288	62.8
	50% L_{max}			**25% L_{max}**		
center	0.275	0.291	51.3	0.276	0.296	25.2
2	0.273	0.287	45.6	0.272	0.289	22.4
3	0.277	0.293	48.7	0.278	0.297	23.9
4	0.275	0.286	30.6	0.278	0.289	14.7
6	0.274	0.288	37.8	0.276	0.292	18.8
8	0.277	0.295	41.4	0.276	0.300	20.9
9	0.277	0.293	46.3	0.277	0.298	23.4
10	0.272	0.290	44.2	0.270	0.293	22.0
12	0.270	0.289	41.4	0.269	0.292	20.1

Analysis: Determine the time required for each display to achieve white stability at the specified intensity levels at each spatial location.

Determine the color gamut for the display at the each of the four intensities. Compute luminance and color variation over the screen relative to screen center for each target luminance level.

The variation may be expressed as chroma difference in terms of CIELuv Δu^*, Δv^* units [Defined in Appendix C].

$$\Delta C^*_{uv} = [(\Delta u^*)^2 + (\Delta v^*)^2]^{1/2}$$

Optionally, the variation may be expressed in terms of CIELab or CIELuv ΔE units which quantify the combined perceived lightness and color of the display [Appendix C].

Accuracy: Luminance measurement accuracy is ± 10% [MPR 1990:8]. Photometer accuracy is at least ±5%. Use a measurement field covering at least 10 scanning lines for raster luminance measurement [TEPAC Publ.105].

Luminance uniformity measurement results obtained by different laboratories agree to within 2%. Uncertainty of the luminance uniformity measurement is 2%. Color uniformity measurement results obtained by different laboratories agree to within 1%. Uncertainty of the color uniformity measurement is 1%.

4.5 Reflectance

Objective: Determine the reflection coefficients of the display screen to enable the user to calculate whether the display will provide contrast modulation required for performing tasks in a particular ambient light.

Procedure: Measure the display reflectance according to the procedures outlined in Section 4.5 Reflectance in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

4.6 Halation

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding, more luminous, areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. Determine what percentage of light is piped into the dark areas as a function of the extent of the surrounding light areas. The results can be used in combination with the measured values of the reflection factor to obtain estimates of contrast ratio that include the effects of both halation and diffuse reflection of ambient light.

Procedure: Follow the recommendations outlined in Section 4.6 Halation in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

4.7 Contrast Ratio

Objective: Calculate large area contrast ratio using measured results for halation and screen reflectance. Measure the contribution of halation to contrast degradation.

Procedure: Follow the recommendations outlined in Section 4.7 Contrast Ratio in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

4.8 Lifetest

Objective: Over time, measure the changes in nonlinear photometric characteristic (output luminance versus input drive) of the display as it spans L_{min} to L_{max}. Determine changes in gamma value over time.

Procedure: Follow the recommendations outlined in Section 4.8 Lifetest in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

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5.0 RESOLUTION CHARACTERIZATION

5.1 Line Width

Objective: Characterize line width profile of the CRT display. For color displays, characterize line width profile in the presence of the shadow mask for individual beams and for combined beams to include effects of misconvergence. This measurement is used for the determination of resolution. The relationship between vertical and horizontal line width is an indication of the beam spot (pixel) shape. Luminance calibration is not required for this measurement unless absolute luminance is measured.

References:

TEP105-7-A, *Line Profile Measurements in Monochrome CRTs*, EIA, 1987.

TEP105-9, *Line Profile Measurements in Shadowmask and Other Structured Screen CRTs*, EIA, 1987.

TEP192, *The Glossary of CRT Terms and Definitions*, EIA, 1984.

TEB25, *A Survey of Data Display CRT Resolution Measurement Techniques*, EIA, 1985.

TEB27, *Relating Display Resolution and Addressability*, EIA, 1988.

Beaton and Farley, *Display Measurement Issues in the ANSI/HFS 100-1988 Standard*, SID'91 Digest, p. 648.

Farrell, Richard J., and Booth, John M., *Design Handbook for Imagery Interpretation Equipment*, Boeing Aerospace Co., 1984.

ARP1782, *Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays*, SAE, January 1989.

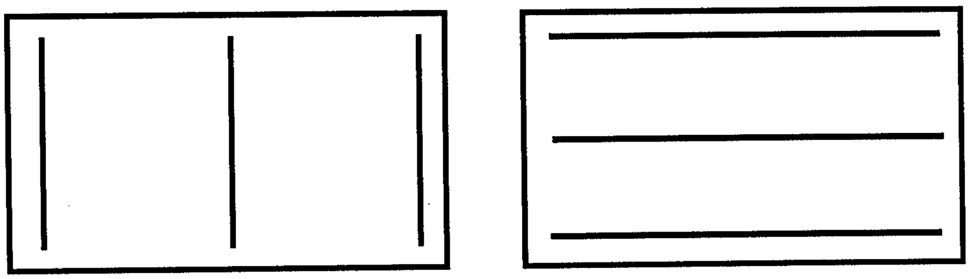
ISO/TC159/SC4 WG2/N219 *Final Text for IS 9241, Part 3—Visual Displays*, December 1990.

VESA Standard: Display Specifications and Test Procedures, Version 1.0, Rev. 1.0 , 3 October 1994.

Equipment:

Video generator
Spatially calibrated CCD or diode optics
Photoptic filter adapter

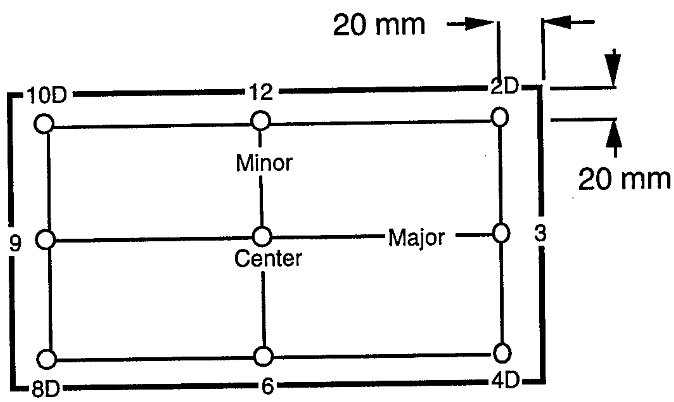
Test pattern: Use the three-line pattern in Figure 5.1-1 to display vertical or horizontal lines each 1-pixel wide. Position lines in video to each test location as shown in Figure 5.1-2. Clock positions reference test positions which are symmetrically spaced 20 mm inside the addressable screen edges. The locations of corner screen test points are arbitrarily defined to be severe enough to adequately evaluate the resolution capabilities of CRTs used to display high pixel-density imagery.



1-pixel wide lines for monochrome and color CRTs

Three-line grille test patterns

Figure 5.1-1



Nine screen test locations

Figure 5.1-2

Procedure: Use moving beam method, scanning slit method, or photodiode (or CCD) array to measure full-width at half-maximum (FWHM) vertical and horizontal white line widths as displayed using single-line video test pattern. Use CCD or diode optic module with photopic filter to measure width at 5% and 50% peak luminance of line profiles for horizontal and vertical lines displayed at 50% L_{max} at nine (9) screen locations: center, ends of major and minor axes, and four corners. Optionally, measure individual red, green, and blue lines.

Screen Sampling

The measurement of linewidth on a structured color CRT screen is complicated by the sampling of the mask and phosphor pattern. In order to account for the variation in apparent linewidth caused by the sampling (and the phase differences between image information and phosphor pattern), and to represent what a viewer actually sees on the screen, linewidth measurements at any screen position are taken on single-pixel wide lines successively moved by one-pixel width to seven different locations. Use a programmable video generator to reposition lines over a range of at least ±3 pixel locations nearest the test point to obtain line width mea-surements over a full cycle of shadow-mask sampling.

Curve fitting

For color displays, the luminance profile of a line measured through the apertures of a shadowmask consists of luminance peaks like those shown in Figure 5.1-3 with spatial frequency equal to the phosphor pitch. For this kind of data, use straight line segments to connect the luminance peaks, then determine the FWHM linewidth on the reconstructed profile [ISO 9241, Part 3]. Optionally, a Gaussian curve fitted to the data points along the measured luminance distribution profile may be used, <u>but with extreme caution!</u>

<u>Optional measure of line width with brightness</u>: Obtain line width measurement for individual beams and white at screen center only for four video input levels corresponding to: 25%, 50%, 75%, and 100% L_{max} as determined in Section 3.0 Initial Monitor Set-up.

Data: Sample deflected Line Width Measurements (measure both horizontal and vertical lines)

Table 5.1-I Linewidth (FWHM) in mm for White Lines at 50% L_{max}, Measured with Photopic Filter.

	H	ΔH	V	ΔV	H	ΔH	V	ΔV	H	ΔH	V	ΔV
W	0.399	0.064	0.290	0.038	0.249	0.058	0.325	0.018	0.348	0.038	0.315	0.058
W	0.348	0.069	0.254	0.043	0.328	0.117	0.287	0.041	0.373	0.079	0.254	0.048
W	0.368	0.046	0.262	0.023	0.246	0.089	0.310	0.051	0.394	0.061	0.259	0.051

Screen positions are indicated by position in sub-table.
H = Horizontal width of vertical lines (mean of seven runs).
V = Vertical height of horizontal lines (mean of seven runs).
ΔH, ΔV = range = max-min of seven runs. **W** = White (with photopic filter).

Analysis: Quantify line width uniformity by reporting vertical and horizontal line widths separately (H x V). Report line width data in same format as Table 5.1-II below.

50% Linewidth (HxV):	
center	0.328 x 0.287 mm (12.9 x 11.3 mils)
average periphery	0.340 x 0.284 mm (13.4 x 11.2 mils)
worst location (@ 10:00)	0.399 x 0.290 mm (15.7 x 11.4 mils)

Table 5.1-II Sample reported linewidth data

Worst location is defined as the test location on the screen where the maximum combined horizontal and vertical linewidth occurs. The combined linewidth is the magnitude calculated using square-root of the sum of the squares:

$$(H^2 + V^2)^{1/2}$$

where H is horizontal linewidth and V is vertical linewidth of white lines.

Optional line width measurements at 50% level in RAR [TEB27]

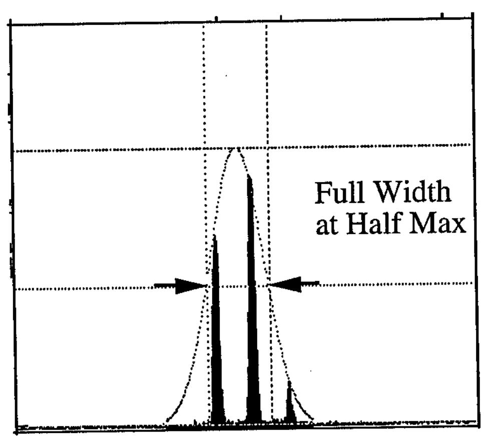
Report horizontal and vertical line widths as Resolution-Addressability Ratio (RAR) at nine screen positions:

$$\mathbf{RAR = R / A}$$

where:

R = full width at half maximum of the line.
A = inter-pixel distance

Output: See sample Figure 5.1-3.



Sample display of line width measurement using diode optics and gaussian curve fit on color screen

Figure 5.1-3

Accuracy: For shadowmask CRTs, a reported linewidth value ±10% is acceptable [ISO 9241, Part 3]. Linewidth measurement results obtained by different laboratories agree to within 0.05mm. Uncertainty of the linewidth measurement is 9%.

5.2 Contrast Modulation

Objective: Quantify luminance spatial frequency effects as a function of spatial frequency and screen position through measurements of luminance profiles. Measure contrast modulation in both horizontal and vertical directions as a function of spatial frequency over a range of luminance levels of the CRT display. This measurement is required for the determination of resolution, and provides information on the large and small signal handling capabilities of the display system. Spatial resolution capabilities of the display may or may not be closely correlated with the addressability. Spatial resolution in color displays is a function of the addressability, the size and shape of the spot, misconvergence, misregistry, and phosphor pitch.

References:

ARP1782, *Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays*, SAE, January 1989.

Austin, R.L., and Otto, H.J., *A Technique for Precision Measurement of Display Spatial Profiles*, SID '87 Digest, pp. 206 - 210.

Beaton and Farley, *Display Measurement Issues in the ANSI/HFS 100-1988 Standard*, SID'91 Digest, p. 648.

Briggs, S. J., *Soft Copy Display of Electro-Optical Imagery,* SPIE Vol. 762 Electro-Optical Imaging Systems Integration (1987), pp 153-170.

ISO 9241 Part 3—Visual Displays, *"Visual Display Terminals (VDTs) Used for Office Tasks—Ergonomic Requirements; and Part 3—Visual Displays, "Final Text*" as of June 1992.

TEB25, *A Survey of Data Display CRT Resolution Measurement Techniques*, EIA, 1985.

TEB27, *Relating Display Resolution and Addressability*, EIA, 1988.

TEP105-9, *Line Profile Measurements in Shadowmask and Other Structured Screen CRTs*, EIA, 1987.

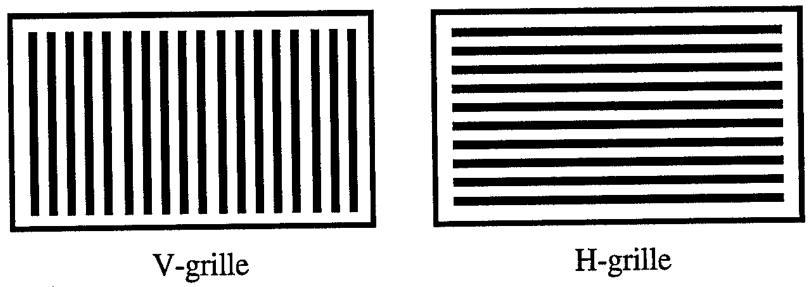
Miller, A. and Murray, W.J., *Fourier-Transform Methods for Determination of Contrast-Modulation Indices from Luminance-Variation Data* SID 94 Digest, pp 531-534.

O'Callaghan, J.P., and Veron, H., *A New Approach for Analyzing the Visual Resolution Characteristics of Shadow-Mask CRT Monitor Configurations*, SID'89 Digest, pp. 208 - 211.

Veron, H., *The Measurement of Resolution of Shadow-Mask CRTs*, SID'85 Digest, pp. 298 - 301.

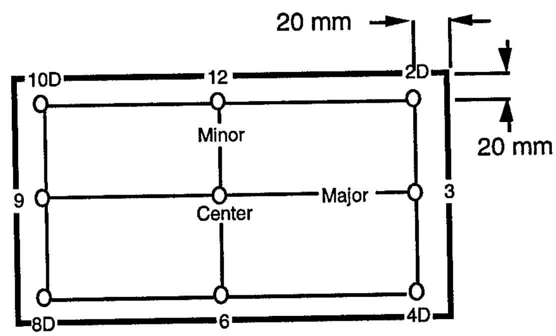
VESA Standard: Display Specifications and Test Procedures, Version 1.0, Rev. 1.0, 3 October 1994.

Test Pattern: Use grille patterns of alternating pixel groupings forming either vertical lines or horizontal lines on the CRT display as shown in Figure 5.2-1.



Full screen level-p/level-v grille test patterns

Figure 5.2-1



Nine screen test locations.

Figure 5.2-2

Grille patterns must be displayed using input counts for Level-p and Level-v pixels which are previously determined in Section 3.0 Initial Monitor Setup. Each successive pattern of horizontal and vertical lines exhibits increasingly higher spatial frequency. Use video patterns of lines 3-pixels at Level-p, 3-pixels Level-v then 2-pixels at Level-p, 2-pixels at Level-v, and 1-pixel at Level-p, 1-pixel at Level-v. Also, display a flat field pattern at Level-p and measure the contrast modulation perpendicular to the scan lines.

Procedure: Follow the recommendations outlined in Section 5.2 Contrast Modulation in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

Shadow mask

From the specified dimensions of the monitor raster, the number of pixels in each direction, and the shadow mask pitch, calculate, for both the horizontal and vertical direction, the spacing between adjacent rows or columns of sampling apertures in the shadow mask, and the spacing between adjacent pixels. Calculate, in each direction, the ratio of the pixel spacing to the sampling aperture spacing.

Example: The data cited here are for a commercial 19-inch diagonal monitor with a 1280 x 1024 pixel landscape-format display, a raster with dimensions 13.48" x 10.79" (342.4 x 274.1 mm), and a delta shadow mask with 12.20 mils (0.31 mm) pitch.

<u>Pixel spacings:</u>

13.48" x 1000/1280 = 10.53 mils (0.2675 mm) horizontal
10.79" x 1000/1024 = 10.54 mils (0.2677 mm) vertical

<u>Sampling aperture spacings:</u>

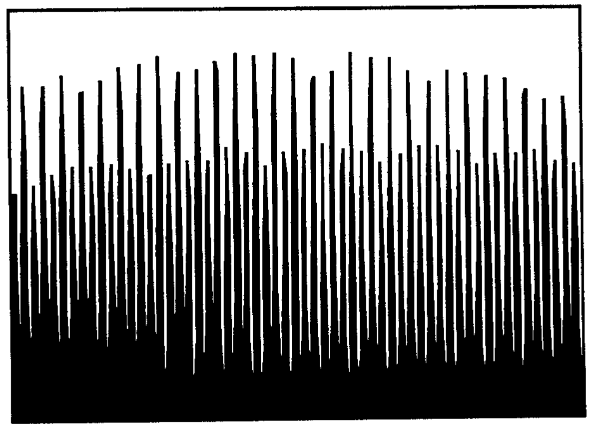
12.20sin(60°) = 10.57 mils (0.2684 mm) horizontal
12.20cos(60°) = 6.10 mils (0.155 mm) vertical

<u>Spacing ratios:</u>

10.53/10.57 = 0.996 horizontal
10.54/6.10 = 1.727 vertical

The occurrence of ratios close to simple rational numbers, and particularly, of ratios close to unity as in the above example, indicate that the monitor may exhibit severe moiré or other aliasing effects. Figure 5.2-3 shows a luminance distribution with one-pixel on and one-pixel off along the horizontal direction measured for this monitor. The alternating sequence of high and low peaks indicates little if any shift in the phase between the pixel pattern and the aperture-mask sampling over the entire range of the measured pattern. The pixel and sampling spacings are equal to within 1 percent. The ratio between the amplitudes of alternating peaks, and consequently the effective contrast modulation at any screen position, is a sensitive function of, e.g., the centration of the raster or the ambient magnetic field. A ratio of the pixel spacing to the sampling aperture spacing of close to 3/2 can also lead to especially undesirable behavior. In this case components at the pixel spatial frequency (e.g., the scan line pattern) and the sampling spatial frequency can interact to produce a response at the spatial frequency corresponding to one-pixel on and one-pixel off, even though no such component is present in the input.

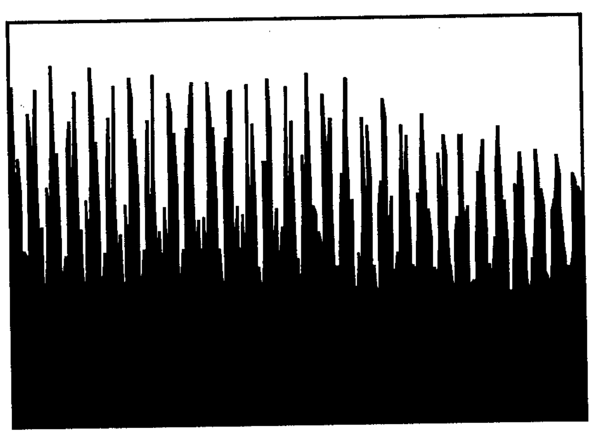
Use, as appropriate, either the L_{peak}/L_{valley}, or Fourier-transform procedure specified in Section 5.2 Contrast Modulation in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0* to measure the contrast modulation with white (tricolor) patterns. A photopic filter should be employed to match the spectral response of the photodetector to that of a standard observer. Figure 5.2-4 shows a measured luminance distribution for which the L_{peak}/L_{valley} procedure is difficult or inappropriate to apply, but for which the Fourier-transform procedure may be used in a straightforward way. Figure 5.2-3 shows a distribution for which either procedure is appropriate.



Measured luminance distribution for a one-pixel on, one-pixel off pattern on a monitor with nearly equal pixel and aperture sampling spacings.

Figure 5.2-3

If it is possible to implement on the particular monitor being tested, a moving-beam method, such as that described in TEPAC Publication TEP105-9, *Line Profile Measurements in Shadowmask and Other Structured Screen CRTs*, EIA 1987 may be used to eliminate shadow mask sampling effects. Figure 5.2-5 illustrates data that can be obtained by this method. The results of such measurements have to be applied with caution when the ratio between pixel and sampling aperture spacings is close to a simple rational number.

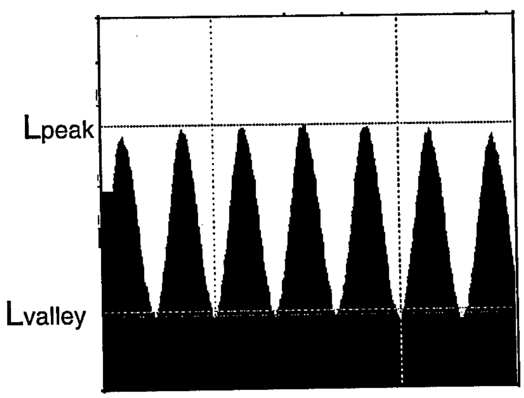


Measured luminance distribution for which Fourier-transform procedure can be applied in a straightforward way.

Figure 5.2-4

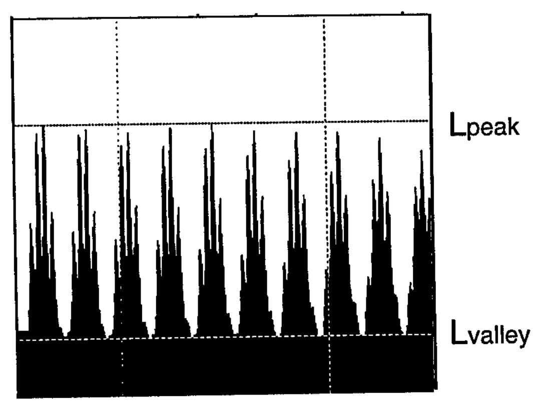
Optionally perform contrast modulation measurements for individual red, green, and blue beams by the procedure selected above. A photopic filter is not required for these measurements.

<ins>If it is desired to use a single procedure for all contrast modulation methods, the Fourier-transform method is recommended</ins> because it is applicable in the greatest variety of cases, and because the results of the procedure, which are analogous to the optical **Modulation Transfer Function**, provide a quantitative interface with application-specific evaluations of monitor performance.



Sample display of contrast ratio using moving beam method to eliminate shadowmask sampling

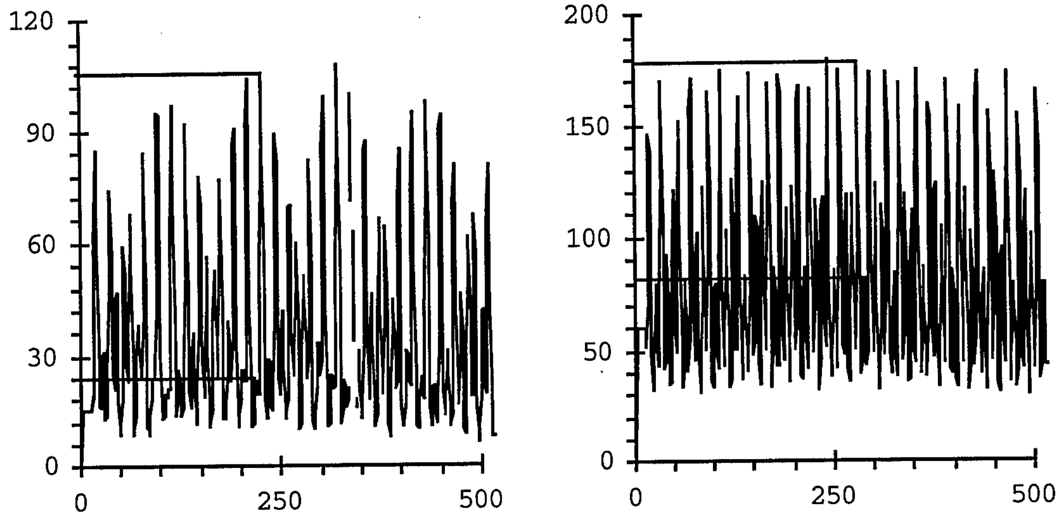
Figure 5.2-5



Sample display of contrast ratio measurements using diode array optics on shadowmask color screen

Figure 5.2-6

The sample contrast modulations shown in Figure 5.2-7 are not fully realized because of the presence of moiré caused by aliasing between the image and the shadowmask. <ins>Because contrast modulation values are calculated for the maximum peak and minimum valley luminance levels as indicated in the sample data shown, they do not include the degrading effects of aliasing.</ins>



Monitor A
0.28mm dot pitch

Monitor B
0.26mm dot pitch

Contrast modulation for sample luminance profiles (1-pixel at level 50, 1-pixel at level 0) for monitors exhibiting moiré due to aliasing.

Figure 5.2-7

Moiré occurs when the phosphor pitch is too large in comparison to the pixel size. Studies have shown that a phosphor pitch of about 0.6 pixels or less is required for adequate visibility of image information without interference from the phosphor structure. In Figure 5.2-7, the Monitor A phosphor pitch is 0.90 pixels as compared with 0.84 pixels in Monitor B. Moiré is more visible in Monitor A, appearing as long stripes where contrast modulation has been degraded. In Monitor B, moiré is less visible, appearing as "fish-scales" where contrast modulation has been reduced. Even though Monitor A exhibits a greater loss of contrast modulation from the presence of moiré on 1-on/1-off vertical grille patterns, there is little or no visual impact when aerial photographic images are displayed. NIDL experts in human vision and psychophysics were unable to discern presence of moiré on either monitor when grayscale imagery was displayed.

Accuracy: Mask structures in color CRTs may prohibit sufficient beam sampling to accurately determine L_{peak} and L_{valley} intensity levels. Improved accuracy can be achieved by using either the Fourier-transform procedure, or the moving-beam method of measurement to eliminate shadow mask sampling effects. The Fourier-transform procedure provides an estimate of contrast modulation that includes the possible reduction of modulation depth at the measurement site on the screen due to the effects of shadowmask aliasing. The moving-beam method, on the other hand, does not capture these effects. Contrast modulation results obtained by different laboratories agree to within 5%. Uncertainty of the contrast modulation measurement is 5%.

5.3 Convergence

Objective: Characterize three-beam convergence of the color CRT display. Misconvergence effects the true appearance of colored features in an image and can contribute to the loss of resolution of the display.

References: Wojtowicz, *Utilization of Symmetry in CRT/Yoke Manufacture and Analysis*, SID'91 Digest, p.886.

ISO/TC159/SC4 WG2/N219, *Final Text for ISO 9241, Part 3—Visual Displays*, December 1990.

Kawakami, Y., and Palmer, W., *High-Accuracy Convergence Measurements*, SID Seminar Lecture Notes, Vol. I: May 6, 1991, pp. M5/1 - M-/26.

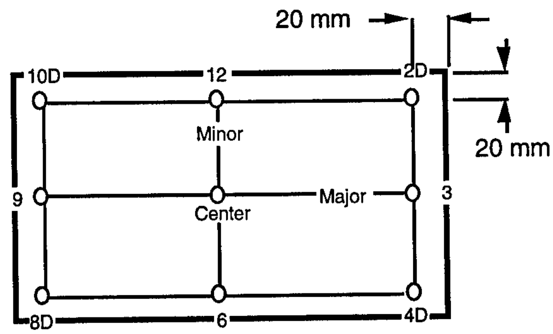
VESA Standard: *Display Specifications and Test Procedures Version 1.0, Rev. 1.0* , 3 October 1994.

Equipment:
- Video generator;
- Spatially calibrated CCD or photodiode array optic module;
- Calibrated X-Y translation stage.

Test pattern: For visual examination, inspect convergence using crosshatch pattern consisting of vertical and horizontal lines each 1-pixel wide, spaced 5% of the screen width/height apart as shown in Figure 5.3-2. For optical measurement at standard test locations shown in Figure 5.3-1, use V-grille and H-grille video patterns consisting of vertical and horizontal lines each 3 to 5-pixels wide as illustrated in Figure 5.3-4. Use of lines greater than 1 or 2-pixels increases luminance profile sampling and improves measurement repeatability on shadowmask CRTs.

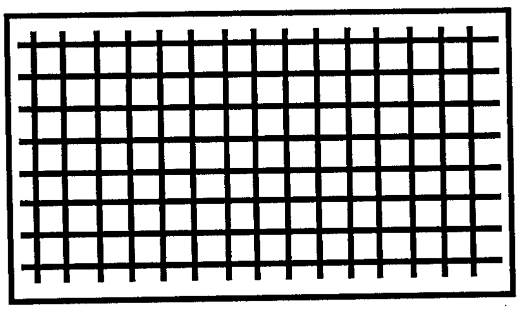
Clock positions shown in Figure 5.3-3 reference test positions which are symmetrically spaced to encompass the entire viewable display area. The D-points are located 20 mm in from the top/bottom and side edges of the viewable phosphor screen. The center point is located at the mechanical center of the screen. All other points including the A points are equally spaced in-between along imaginary lines forming a 5x5 grid not shown.

The locations of corner screen test points are arbitrarily defined to be severe enough to adequately evaluate the resolution capabilities of CRTs used to display high pixel-density imagery.



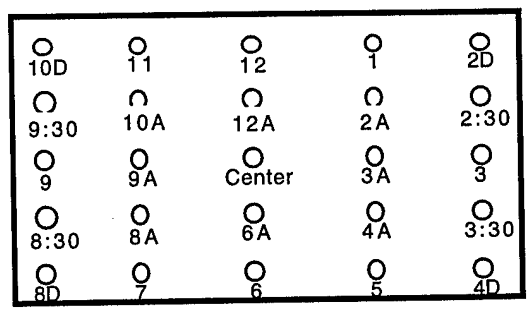
Nine screen test locations.

Figure 5.3-1



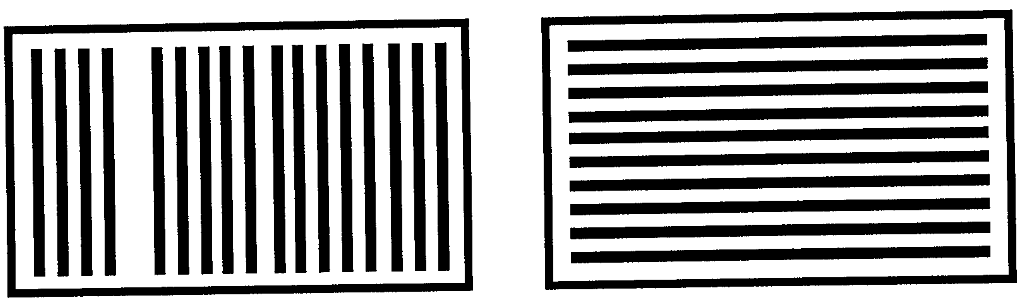
Crosshatch test pattern

Figure 5.3-2



Twenty-five Screen test locations

Figure 5.3-3



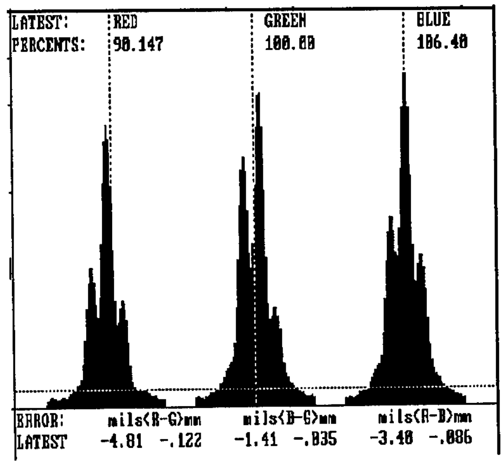
V-grille H-grille

5-pixel wide lines

Grille test patterns

Figure 5.3-4

Procedure: Use optic module and x-y translation stage to measure x and y separations between centroids of 3 to 5-pixel wide vertical and horizontal lines for blue with-respect-to red, and optionally green with-respect-to red. Measure vertical and horizontal misconvergence at nine standard screen test points, optionally twenty-five (25) screen test points shown in Figure 5.3-3 using grille video test patterns illustrated in Figure 5.3-4. Visually examine overall convergence performance using a finer crosshatch pattern as shown in Figure 5.3-2. Record measurements at any screen location where significant misconvergence is apparent, but not characterizable at the standard twenty-five screen test locations.



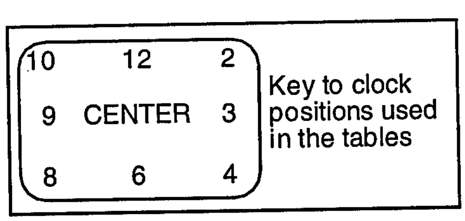
Sample display of convergence measurements using diode optics on a color dot screen

Figure 5.3-5

Data: Misconvergence measurements are arranged by screen position in Table 5.3-I, and are reported in mm and in pixels.

Table 5.3-I. Sample Blue-to-Red Misconvergence. Misconvergence (in mm) is at the Maximum Luminance for a Three-pixel Line. Values Given are the Mean of Five Runs.

Position		**Horizontal Separation**		**Vertical Separation**	
		mm	**pixels**	**mm**	**pixels**
Center		-0.061	-0.3	0.109	0.5
Minor Axis	6	-0.003	-0.01	0.201	0.8
	12	0.038	0.2	0.089	0.4
Major Axis	3	-0.130	-0.5	0.213	0.9
	9	-0.089	-0.4	0.201	0.8
Corners	2	-0.086	-0.4	0.287	1.2
	4	-0.231	-1.0	0.170	0.7
	8	-0.371	-1.6	0.229	1.0
	10	-0.343	-1.4	0.142	0.6
Average magnitude		0.150	0.65	0.182	0.77



Analysis: Quantify convergence uniformity by reporting vertical and horizontal misconvergence separately (H x V). Report convergence data in same format as Table 5.3-II below.

Table 5.3-II Sample reported convergence data

Convergence (HxV):	
center	0.061 x 0.109 mm (2.4 x 4.3 mils)
average periphery	0.163 x 0.168 mm (6.4 x 6.6 mils)
worst location (@ 8:00)	0.371 x 0.229 mm (14.6 x 9.0 mils)

Worst location is defined as the test location on the screen where the maximum combined horizontal and vertical convergence errors occur. The combined error is the magnitude calculated using the square-root of the sum of the squares:

$$(H^2 + V^2)^{1/2},$$

where:

H is horizontal separation
V is vertical separation of blue with-respect-to-red lines.

Optionally, symmetrize misconvergence data [Wojtowicz]. Quantify design misconvergence with symmetric components of convergence data. Quantify manufacturing and set-up errors with asymmetric components of convergence data.

Accuracy: Convergence measurement results obtained by different laboratories agree to within 0.05 mm. Uncertainty of the convergence measurement is 0.05 mm.

Large-size CRTs typically exhibit 1 mm or more misconvergence error as a function of inter-beam space charge repulsion. Misconvergence effects due to space charge are not present when red, green and blue beams are displayed sequentially. Misconvergence effects due to space charge can be measured, however, by using CRT measurement systems which are capable of determining misconvergence of a displayed three-beam white line test pattern. Such systems are commercially available.

5.4 Moiré

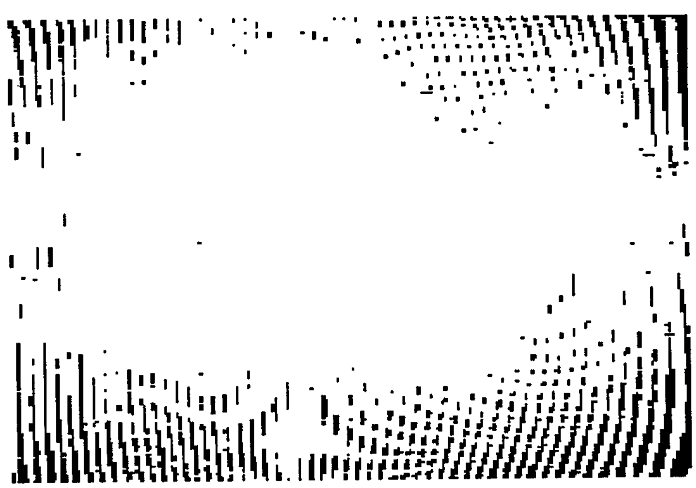
Objective: For color displays, qualitatively characterize luminance spatial effects resulting from the mixing of the spatial frequencies of the shadow mask pitch and the beam spot size by making visual observations of various test patterns on the display. Moiré has the capacity to deteriorate resolution of high frequency information in images on the display by superimposing shaded wavy patterns on the image. Moiré patterns occur when the beam 5% spot size is less than 2.5 to 2.6 times the mask pitch [TEPAC 105-9]. Other studies have shown that a phosphor pitch of 0.6 pixels or less is required to maintain the visibility of image information without interference from the phosphor structure at any spatial frequency.

References: Wittke, *Moiré Considerations in Shadow Mask Picture Tubes*, SID'87 Digest, p.347.

Benson, K. Blair., Television Engineering Handbook , McGraw-Hill Book Co., 1986, p.127.

TEPAC 105-9, *Line Profile Measurements in Shadow Mask and Other Structured Screen Cathode Ray Tubes,* EIA, January 1987.

Procedure: Inspect the display for variations in luminance levels that are visually noticeable as alternating lighted and shaded stripes of Moiré patterns of spatial frequencies between < 1 and ~ 25 cycles per inch of display screen area. An example of Moiré patterns on a color CRT is shown in Figure 5.4-1 below.



Moiré patterns on a color CRT

Figure 5.4-1.

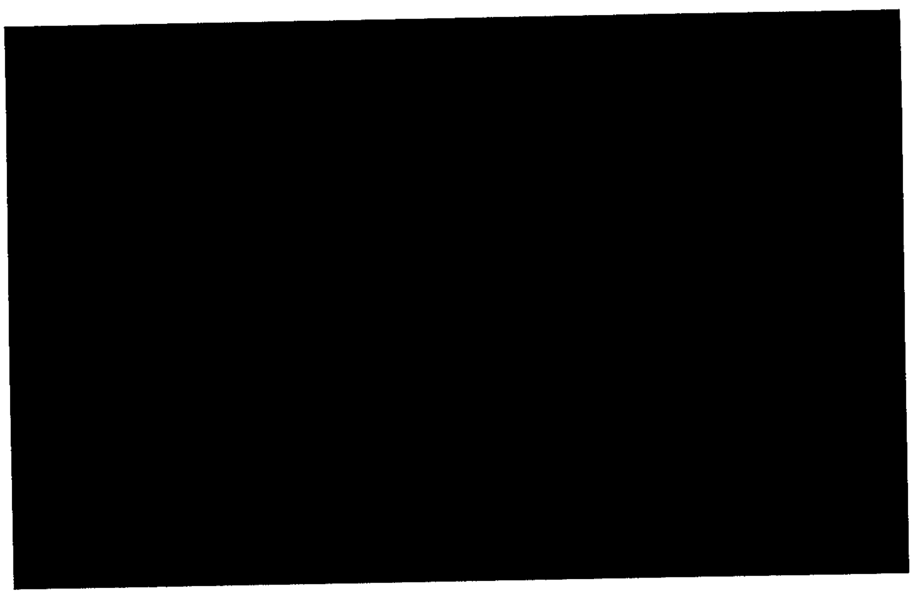
Inspect for Moiré using green beam at 50% L_{max} using the input count level determined in Section 3.0. Record occurrences at each of nine standard screen locations where noticeable Moiré is observed.

A procedure is described below for making modulation-depth measurements on moiré patterns if desired, using an array detector (e.g., CCD or diode).

Preliminary statements should be made about the following items:

- Illumination from a single beam should be used in making the measurements.
- The depth of the modulation depends on the beam profile. One might wish therefore to make measurements:
    - ~ at different beam currents;
    - ~ at different parts of the screen;
    - ~ for each of the three beams.
- Provisions should be made to determine the location of the display pattern that is imaged on the detector array. For example, strips of opaque adhesive tape can be placed on the face of the display to establish boundaries, or to serve as fiducials.

The detector should be positioned at a sufficient distance from the display to obtain an image of appropriate magnification. (For example, the magnification might be such that the image of the desired region is about one-half the size of the detector array.) The use of a zoom lens would permit various magnifications to be chosen without repositioning the detector head.



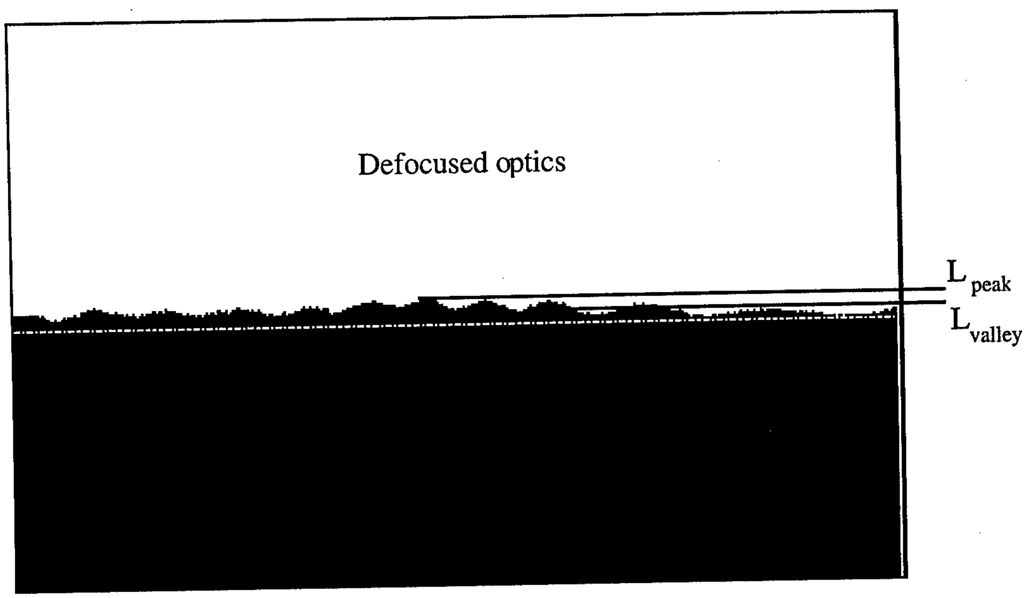
Luminance profile of moiré using focused optics contains high spatial frequencies of phosphor pitch.

Figure 5.4-2

Initially, the lens on the detector head should be focused to produce a sharp image of the display as shown in the sample output in Figure 5.4-2. In this condition there are aliasing effects due to the beating of spatial frequencies in the screen

pattern (electron beam and shadowmask) with those due to the spacing of the elements in the detector array. The detector output at this stage is unsuitable for measurement of the modulation depth of the moiré pattern.

The fine structure can be significantly reduced by integrating over a suitable number of neighboring elements in the detector array. This is conveniently accomplished by slightly defocusing the lens. As the lens is gradually defocused, the aliasing pattern quickly disappears, and, as shown in the sample output in Figure 5.4-3, the detector output closely represents the intensity variation of the moiré pattern. (The moiré patterns of interest have much smaller spatial frequencies than those of the electron beam pattern, the shadowmask, or the detector array elements, and are little affected by the defocusing. The required degree of defocusing is not critical; it is observed that as the focus is changed, the modulation depth of the detector output remains on a "plateau".)



Profile of moiré using slightly defocused optics to filter out high spatial frequency effects of phosphor pitch.

Figure 5.4-3

As the amount of defocusing is further increased, the modulation depth in the detector output begins to decrease. The lens should then be brought back towards the sharp focus setting until the "plateau" condition is restored It should be confirmed that the number of peaks in the detector output corresponds to what is perceived by eye on the bounded region of the display. The modulation depth of the detector output is then measured and recorded.

Data: Record occurrences of visually noticeable Moiré for grille test patterns displayed at 50% L_{max} (using the input count level determined in Section 3.0) over a range of spatial frequencies.

Table 5.4-I. Sample sheet for Recording Occurrences of Moiré

	Noticeable Moiré indicate by √		
Grille:	3 on x 3 off	2 on x 2 off	1 on x 1 off
Location			
Center			
2		√	√
3		√	√
4			√
6			
8			√
9			
10		√	√
12			

Analysis: TBD

6.0 Geometric Characterization

6.1 Waviness

Objective: Measure center (green) beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols. The presence of waviness also causes large area raster distortions including pincushion, trapezoid (keystone), rotation and orthogonality.

Procedure: For color CRT displays, measure waviness of the green beam according to the procedures outlined in Section 6.1 Waviness in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

6.2 Linearity

Objective: Measure the relation between the actual position of a pixel on the screen and the addressed position to quantify effects of raster nonlinearity. Nonlinearity can be expressed as a variable pixel density Nonlinearity of scan degrades the preservation of scale in images across the display.

Procedure: For color CRT displays, measure linearity of the green beam according to the procedures outlined in Section 6.2 Linearity in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

6.3 Raster Size Stability

Objective: Assess the stability of the high voltage supply by measuring the change of raster size as a function of the average luminance of the display. Since more current is required at higher luminance, the accelerating voltage will decrease, and thus the size of the raster will increase, if the power supply has less than perfect regulation.

Procedure: For color CRT displays, measure raster size variation of the three-beam white flat field test pattern according to the procedures outlined in Section 6.3 Raster Size Stability in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

6.4 Scan Variability With Time: Jitter, Swim, Drift

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depend upon the amplitude and frequency of the motions which can be caused by imprecise control electronics or external magnetic fields.

Procedure: For color CRT displays, measure raster jitter of the green beam test pattern according to the procedures outlined in Section 6.4 Scan Variability With Time: Jitter, Swim, Drift in NIDL Publication No. 171795-036 *Display Monitor Measurement Methods under discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance, Version 2.0.*

7.0 REPORTING

Objective: A standardized performance certification report for each monitor type that enables users to:

- rapidly ascertain the monitor's performance capabilities;
- easily compare the capabilities of different monitors;
- -- judge the capability of the monitor for meeting their image evaluation needs.

SAMPLE EVALUATION DATASHEET

I. MANUFACTURER'S DATA

Manufacturer Name	Company ABC
Model #	1A
Monochrome or Color	Color
Screen Diagonal	21 inches
Horizontal Scan Rate	89.71 kHz
Vertical Scan Rate	72.00 Hz
Image Size (H x V)	380.0 mm x 284.5 mm (14.96 x 11.20 inches)
Addressable Pixel Number	1600 x 1200
Pixel Size	0.237 x 0.237 mm (9.35 x 9.33 mils)
Dot or Stripe Pitch	0.28mm (11.0 mils)

II. MEASURED PERFORMANCE

A. Performance Related to Luminance

Warmup Time	20 minutes to ±1%
Full Screen Luminance	103 cd/m^2 (30 fL)
Luminance Uniformity	76.67 - 96.13 cd/m^2
Color Coordinates	x = 0.282, y = 0.295
Color Uniformity	2.9% in x, 4.1% in y
System Gamma	W=2.45 R=2.35 G=2.53 B=2.40
Luminance Stability	≤12%

B. Performance Related to Geometry

Waviness	≤ 0.4%
Linearity	≤ 2.6%
Raster Size Stability	≤ 0.1%
Jitter	< 0.13 mm (< 5 mils)

C. Performance Related to Resolution

50% Linewidth (HxV):	
center	0.328 x 0.287 mm (12.9 x 11.3 mils)
average periphery	0.340 x 0.284 mm (13.4 x 11.2 mils)
worst location (@ 10:00)	0.399 x 0.290 mm (15.7 x 11.4 mils)
Convergence (HxV):	
center	0.061 x 0.109 mm (2.4 x 4.3 mils)
average periphery	0.163 x 0.168 mm (6.4 x 6.6 mils)
worst location (@ 8:00)	0.371 x 0.229 mm (14.6 x 9.0 mils)
Faceplate Reflectivity specular	20%
diffuse	3%
Contrast Ratio	75:1
Halation	≤ 5.6%
1-on/1-off Contrast Modulation (HxV):	
center	43 x 31%
average periphery	16 x 38%
worst location (@ 8:00)	6 x 46%
Resolvable Pixels (HxV) (screen average)	
@ C_m = 25%	1412 x 1174
@ C_m = 50%	1047 x 970

D. Reliability and Life Performance

MTBF	10,000 h
Cathode life at 100 cd/m^2 luminance	10,000 h

E. Evaluator

Organization Name	Testing Lab XYZ
Address	Tucson, AZ
Phone	(_ _ _) _ _ _ - _ _ _ _
Evaluation Dates	3/1/93 to 4/1/93
Equipment Used	Photo Research PR-704, Microvision SS100

F. Additional Performance Measurements Available: (Y X / N__)

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Wojtowicz, *Utilization of Symmetry in CRT/Yoke Manufacture and Analysis*, SID'91 Digest, p.886

APPENDIX A
DEFINITIONS OF MEASUREMENT TERMS AND ACRONYMS

Addressability—the inter-pixel distance (TEP192), "addressability" defines how precisely one can position the electron beam spot on the screen.

ARP *Aerospace Recommended Practice* associated with SAE.

ASTM American Society for Testing and Materials

Candelas per square meter (cd/m^2)—metric unit of measurement of luminance. 1 cd/m^2 = 0.2919 Footlambert (fL).

CD color difference

CIE Commission Internationale De l'Eclairage (International Commission on Illumination)

Contrast Modulation, (C_m)—measure of the luminance ratio between the "lit" and "unlit" portions of grille patterns. A grille pattern of given frequency is considered to be resolved when the contrast modulation is greater than 20%.

CRT Cathode Ray Tube

Contrast Transfer Function, (CTF)—curve of contrast modulation values plotted as a function of spatial frequency.

Convergence—measure of the separation in landing positions of separate beams directed toward the same point on the screen. The main misconvergence errors involve blue-to-red separations and green-to-red-blue-average separations (coma), and are measured in both horizontal and vertical directions. Misconvergence errors greater than the pixel size degrade resolution and cause spurious color fringes at edges in images.

EIA Electronic Industries Association

Fill Factor the ratio of "lit" to total active area of a display screen.

High Voltage Regulation—measure of variation of overall raster size with changes in luminance (as caused by changes in electron beam current). High voltage output from a well regulated supply will not change with beam current.

ISO International Standards Organization

Linearity measure of the preservation of the scale of image contents across the screen.

Luminance Stability as a Function of Fill Factor—measure of variation in luminance as a function of the fraction of screen area that is being "lit" (i.e., the fraction of the frame time in which the electron beam is actually turned on).

MPR [Swedish] National Board for Measurement and Testing

Moiré a spurious repetitive luminance pattern observed on displays as a result of the beating of the phosphor structure pattern against the pattern of information imposed on the screen. Moiré is highly visible when the frequencies of the two patterns are comparable. The presence of Moiré destroys contrast modulation, and hence, resolution.

NIDL National Information Display Laboratory

NIST National Institute of Standards and Technology (formerly NBS)

NBS National Bureau of Standards

Pixel picture element

Resolution measure of the ability to discriminate picture detail; i.e., ability to distinguish two adjacent spots on the screen.

Scan Jitter rapid motions of raster on the screen face caused by instabilities in the monitor circuitry.

SID Society for Information Display

Spatial Uniformity of Luminance—measure of how luminance varies across the screen. Luminance should be as uniform as possible.

SWEDAC Swedish Board for Technical Accreditation (formerly MPR)

System Gamma—the slope of the curve in a log-log plot of output luminance vs. input drive.

TEB TEPAC Engineering Bulletin (published by EIA)

TEPAC Tube Engineering Panel Advisory Council (associated with EIA)

TBD To be determined

Warm-up Characteristic—the time required for the luminance to stabilize at some predetermined value; e.g. ±1%.

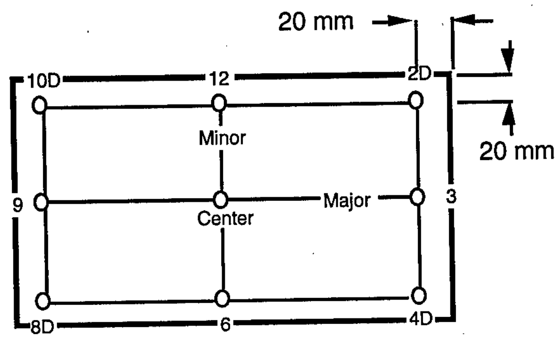
Waviness measure of the degree of curvature of (or departure from) nominally straight lines on the display screen. Principle components of waviness are:

- **Pincushion**—a quadratic distortion
- **Gullwing**—a quartic distortion.

APPENDIX B

SCREEN TEST POINTS: COLOR CRT DISPLAYS

The number and location of screen test points depends on the performance parameter being evaluated, the size of the display screen, and the intended use of the display. This appendix is intended to provide guidance for the use of alternative test points when appropriate.



Nine screen-test-points for routine CRT display evaluation.

Figure B-1.

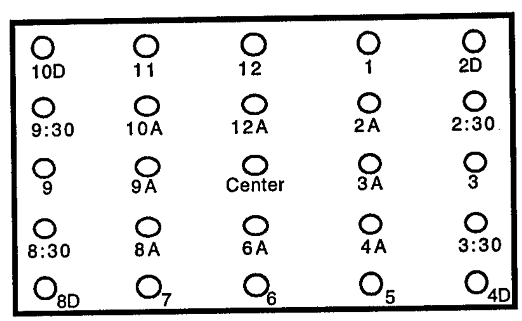
Color CRT Display Considerations

CRT luminance and color performance typically is best at screen center and degrades with screen position towards the periphery. Further, CRT performance in the corner screen locations is generally worse than the performance along the major and minor axes of the screen. CRTs exhibit significant asymmetries in performance errors due to manufacturing and setup; therefore, a complete evaluation of a given performance parameter requires measurements be taken in each of the four quadrants of the CRT screen so that the contributions of each of the asymmetrical parts are taken into account.

Luminance, color uniformity, and color convergence measurements

Use five screen-points located at screen center and four corners, minimum. On the typical CRT, center and corner locations exhibit the best and worst performance, respectively. Measurements at all four corners are required to distinguish asymmetrical properties of the display. Preferably include four additional measurement points located at both ends of major and minor axes of the screen. Typical screen-points are located at mechanical center and 20 mm inward from the viewable edges of the screen as depicted in Figure B-1. When using alternate screen locations, consider that for the typical CRT, luminance usually degrades monotonically between screen center and the periphery.

To exemplify the effect of test-point location on luminance uniformity, luminance was measured at screen center and at points along the 2 o'clock corner diagonal of a 19V color CRT monitor and the results plotted in Figure B-3. This example illustrates the extent to which color CRT luminance uni-formity can vary depending upon exactly where the corner screen measurement location is defined.



Twenty-five screen-test-points to assess convergence and raster distortions during CRT design and factory setup.

Figure B-2.

Increased numbers of test locations are war-ranted for thorough evaluation of very high resolution or large screen size color CRT displays. It is customary to use an arrange-ment of twenty-five or more measurement points as depicted in Figure B-2, making measurements for evaluating raster distortions such as **inner pincushion** or **gullwing**, and **misconvergence** during the CRT design and factory setup stages.

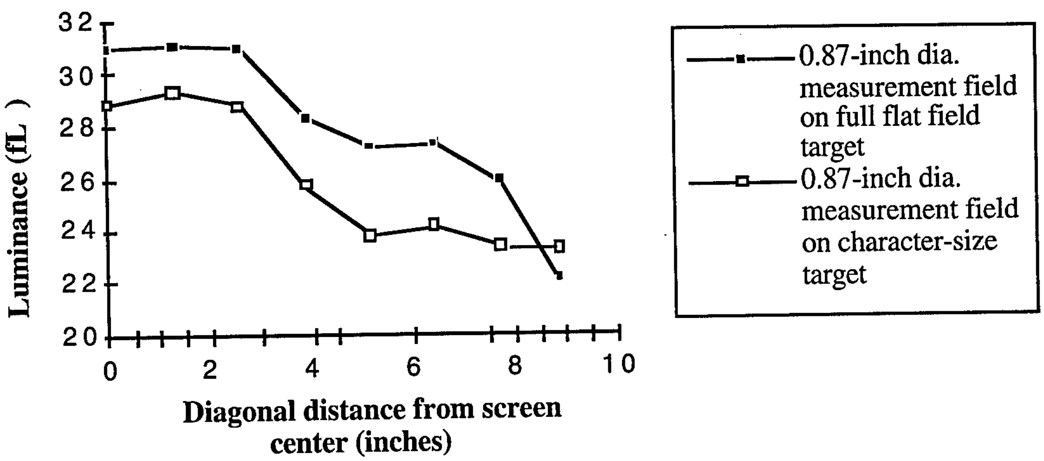
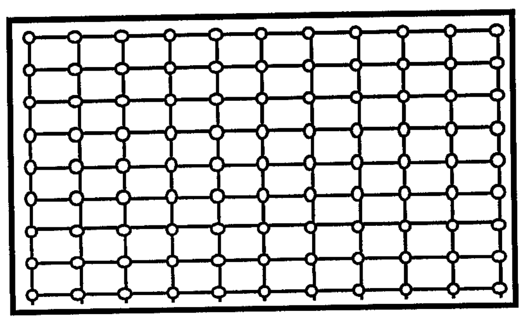


Figure B-2. Luminance measured on character and full screen flat field targets using a character-sized photometer measurement field plotted as a function of screen position. Center-to-corner luminance ratio depends on exact screen locations. Luminance values for full screen target average 7% higher than for character-size target.

Even when the CRT is properly designed, variations in color purity can result when shielding and degaussing fail to compensate for the effects of external magnetic fields. Misregistry variations across the tube face may occur without obvious patterns, and so, it is not uncommon for manufacturers to assess color purity by measuring misregis-try errors at ninety-nine test-points or more as depicted in Figure B-4.



Ninety-nine screen test-points arranged in an 11 x 9 grid for measuring misregistry to assess color purity on a 27V 4 x 3 aspect ratio CRT.

Figure B-4.

APPENDIX C

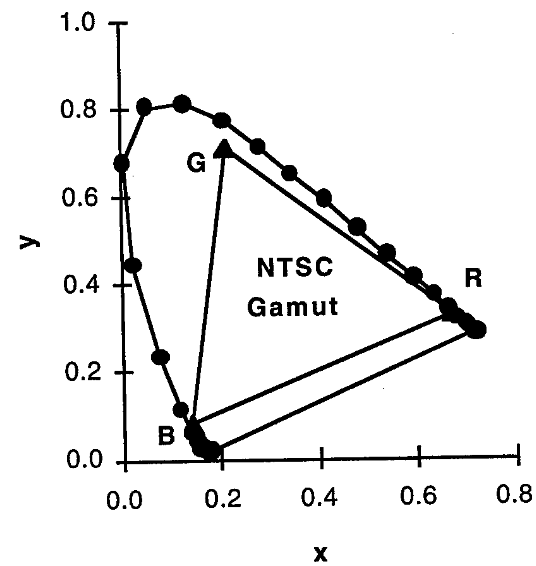
COLORIMETRY AND THE CIELuv DIAGRAM

The following discussion is meant to pro-vide the reader with an introduction to the concepts and terms of colorimetry sufficient to understand their use in this document. The reader is encouraged to refer to the texts listed below for a more thorough coverage of this topic.

The measurement values for the display colors are typically presented in terms of 1931 CIE x, y colorimetry coordinates. These coordinates refer to the horseshoe-shaped diagram in Fig. C-1.

This method of describing colorimetry, while widely used, has two drawbacks. First of all, the space is not visually uniform, i.e. colors equally spaced on the CIE diagram are not perceived as being equally different. Secondly, this presentation does not deal with differences in luminance.

Several approaches to perceptually more uniform spaces, that also include luminance, have been developed, including the CIELab, CIELuv, and Munsell spaces (Judd and Wyszecki, p. 281). Of these the CIELuv space is particularly appropriate for discus-sing monitor performance, because it has a reasonably straightforward relationship with the video concepts of hue and saturation (Sproson, p. 19).

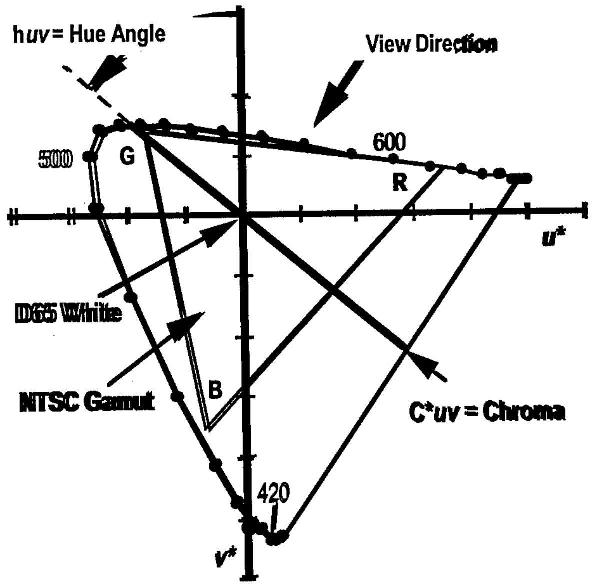


CIE 1931 ***Chromaticity Diagram*** *showing the gamut of the NTSC phosphor set. (Typical monitor gamuts are much smaller; the green point, in particular is much further down and to the right).*

Fig. C-1

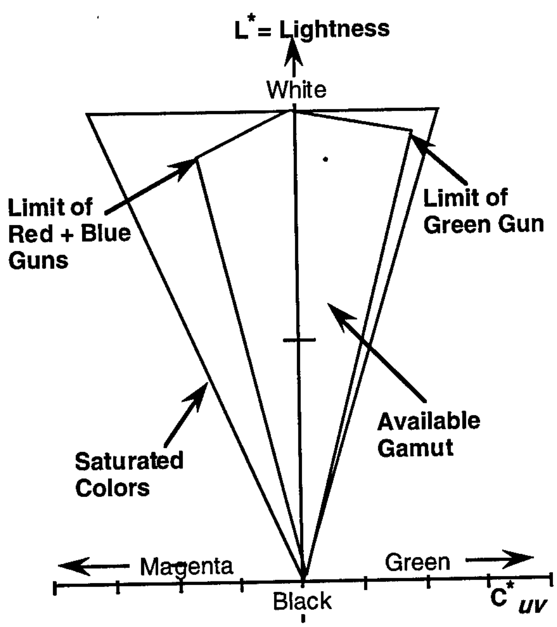
Table C-1
Chromaticity Coordinates and Correlated Color Temperatures for Some Common White Points

CIE Illuminant	Correlated Color Temp (K)	CIE 1931 x, y Chromaticity Coordinates x	y	CIE 1976 u', v' Chromaticity Coordinates u'	v'
A	2856	0.448	0.407	0.256	0.524
B	4874	0.348	0.352	0.214	0.485
C	6774	0.310	0.316	0.201	0.461
D_{55}	5503	0.332	0.348	0.204	0.481
D_{65}	6504	0.313	0.329	0.198	0.468
D_{75}	7504	0.299	0.315	0.193	0.459



The $(u^*,v)^*$ plane centered on the D65 white point showing the NTSC gamut.

Fig. C-2a.



A cut along the lightness axis showing how luminance affects the available gamut. Fig. C-2a shows the viewpoint.

Fig C-2b.

The CIELuv space is built on the perceptually more uniform CIE 1976 (u', v') colorimetry diagram obtained from x and y by the following transformation:

$$u' = 2x/(6y - x + 1.5)$$

$$v' = 4.5y/(6y - x + 1.5)$$

The CIELuv space translates the (u', v') diagram to be centered on the white point (u'_o, v'_o), the new coordinates are designated (u^*, v^*). The white point depends on the display used; typical white points are listed in Table B-1 along with their correlated color temperature. Illuminant C is the NTSC standard white; D_{65} is the PAL standard.

Defining the maximum white luminance as Yo (following the traditional use of the tri-stimulus value Y for luminance), an approximately uniform lightness parameter, L^*, is defined using a cube-root relation. The complete transform set is:

$$L^* = 116\,(Y/Y_0)^{1/3} - 16 \quad Y/Y_0 \geq 0.008856$$

$$L^* = 903.29\,(Y/Y_0) \quad Y/Y_0 \leq 0.008856$$

$$u^* = 13\,L^*\,(u' - u'_o)$$

$$v^* = 13\,L^*\,(v' - v'_o)$$

The CIE 1976 chroma C^*_{uv}, **psychometric saturation** s_{uv} and **hue-angle** h_{uv} for the CIELuv space are:

$$C^*_{uv} = (u^{*2} + v^{*2})^{1/2}$$

$$s_{uv} = C^*_{uv} / L^*$$

$$h_{uv} = \tan^{-1}(v^*/u^*)$$

Figure C-2 shows the (u^*,v^*) plane and a schematic cut along the L^* axis for a typical color CRT. Note that for low L^* the width of the CIELuv cone increases linearly with L^*. The maximum value of Y, corresponding to

where the Δ's in the brackets are the differences between the u^*, and v^* coordinates of the two colors being compared.

Because the space is relatively uniform perceptually, distances in the space between L^*, u, $^*v^*$ points are a reasonable measure of color differences. (MacAdam has shown that a truly uniform space must be non-Euclidean; CIELuv is a Euclidean approximation). Psychophysical studies indicate that one ΔE unit corresponds rough-ly to a just noticeable difference; two points in the space separated by more than 5 ΔC units are clearly distinguishable.

References:

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